SEAT COMPONENT TO PREVENT WHIPLASH INJURY

K.-U. Schmitt[1,2], M. Muser[2], M. Heggendorn[1], P. Niederer[1], and F. Walz[2]

[1] Institute of Biomedical Engineering, University and Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

[2] Working Group on Accident Mechanics, University and Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

Paper No. 224

ABSTRACT

A new seat slide was developed to prevent whiplash injury. The behaviour of the seat during low-speed rear-end impacts is improved. All functions as well as the behaviour of the seat in other impact conditions remain unchanged.

The system consists of a damping mechanism which is triggered by a sensor. A certain vehicle acceleration followed by an impact force extended by the occupant on the seat back is needed to activate the system. Unintended activation is prevented. Once the system is activated, the seat is allowed to move backwards in a purely translational manner while the motion is damped. A distance of approx. 40 mm can effectively reduce the occupant neck loading.

Sled test experiments were performed to analyse the behaviour of the new system. The tests were conducted to mimic rear-end collisions with a delta-v of 16 km/h. A BioRID dummy was used as a human surrogate. The results indicate the beneficial influence of the damping seat slide on the occupant kinematics. In particular the so-called S-shape deformation of the neck assessed by the neck injury criterion NIC_{max} is reduced. Comparing a standard car seat with and without the damping seat slide, it was shown that the NIC_{max} is reduced by approx. 40%.

Hence it was shown that besides the head restraint and the recliner that are used in other whiplash protection systems, also the seat slide has the potential to prevent whiplash injury.

INTRODUCTION

As of today several seat systems are presented that intend to prevent whiplash injury. Simplifying, such systems aim at reducing the relative motion between head and torso as such motion is often suspected to be related to whiplash injury [e.g. Ferrari 1999]. Generally, the systems can be divided into two groups: active and passive systems. Active systems are characterised by a mechanical mechanism that influences the kinematics of the occupant sitting on the seat by allowing or enforcing additional interaction, often a motion of the seat, in case of an impact. The SAHR system [Wiklund and Larsson 1998], for instance, represents an active system. It consists of an active head restraint that automatically moves up and closer to the occupants' head in rear-end impacts. Thus the distance between head and head restraint is reduced. Volvo presented the WHIPS seat [Lundell et al. 1998] which is equipped with a recliner that allows controlled backwards movement of the backrest during rear-end impact. The motion is performed in two steps: a translational rearwards movement of the backrest is followed by a rotational motion reclining the backrest. An other system, called WipGARD [Zellmer et al. 2001], also enables the backrest to perform a translation followed by a rotation. Both the WHIPS and the WipGARD require a critical load to activate the system.

A typical example for a passive system, i.e. a system without mechanical mechanism, is a add-on head restraint padding to reduce the head to head restraint distance. Such additional padding is available from various manufacturers [e.g. ContiTech 2000].

In this study a new active system, a damping seat slide to prevent whiplash injury is presented. A functional model of the seat slide was built and mounted to a standard car seat. Its preventive potential was shown by performing sled test experiments. The system was patented at the European Patent Office (No. EP 05 405 537.8).

MATERIAL AND METHODS

A new seat component was developed based on a standard seat slide as used in a recent car seat. In order to ensure that the basic functions of the seat slide persisted, modifications were not allowed to influence the translational adjustability and the stiffness of the structure. Changes to the fixing of the slide to the car were avoided such that the according regulations like ECE R-17 are still fulfilled. Thus the seat characteristics for other impact conditions than low-speed rear-end are meant to be sustained. Also the seating posture of an occupant had to be maintained with the new device. Furthermore, it was defined that

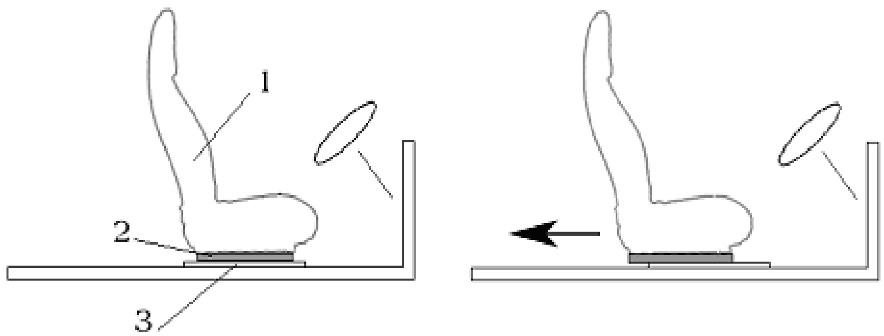

Figure 1. Principle of the seat slide: The seat (1) of a vehicle is mounted to a seat slide (2) which itself is mounted to the car body (3) (left). In case of a rear-end impact, a trigger system releases the new seat slide which then enables the seat to move backwards (relatively to the car) while damping this movement (right).

repairs possibly needed after the new seat slide was activated had to be inexpensive and easy to carry out.

Principle

The relative acceleration between head and T1, and consequently also the NIC_{max} value, is to be reduced to prevent whiplash injury. Therefore a device was developed which allows a translational motion of the seat relative to the car while damping this motion. This leads to a delay of the building up of the torso loading. Thus the main effect is the synchronisation of the loading of the head and the upper torso.
The system is mounted between the seat base and the car floor (Figure 1) and consists of a damping mechanism which is triggered by a sensor. This sensor detects the vehicle acceleration and, when a certain limit is exceeded, the deformable element is released. Additionally, the damping element requires a tripping energy threshold to be deformed. Thus, as a measure to prevent unintended activation, the system needs a certain acceleration followed by an impact force of the occupant against the seat. Once the system is activated, the seat is allowed to move backwards in a purely translational manner while the motion is damped (Figure 2).

Functional model

To show the feasibility of the principle described above, a functional model of the seat slide was developed and incorporated into a standard car seat. A spring-mass system is used to detect the acceleration necessary to activate the system. If the acceleration threshold is reached, the system is released, i.e. a translational motion of the seat relative to the car floor is allowed. In this case the seat slides along a defined path as a gliding part is guided along a slide.
The activation mechanism releases both damping components simultaneously. The damping is performed by deformation of steel profiles on each side of the system, i.e. the mechanism is symmetric (Figure 3). The geometry and strength of the profiles were chosen on the basis of analytical design studies and tensile testing experiments. It has to be noted that due to the material of the profile used, a certain elastic force limit must be exceeded to start the damping. Preferably the profiles show a small elastic range,

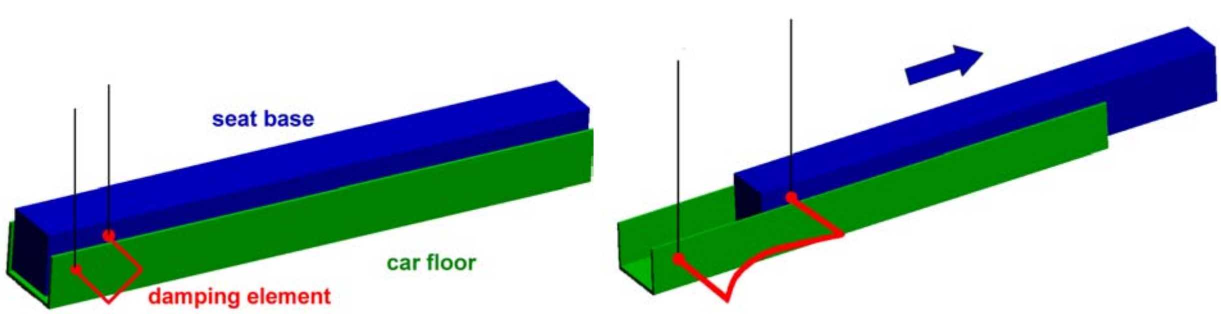

Figure 2. Damping of the translational backwards movement of the seat base relative to the seat; initial state (left) and deformed state (right).

Figure 3. Deformable U-shaped steel profile as used in the functional model; undeformed profile (left) and deformed profile (right).

followed by a large plateau region until eventually a hardening effect is observed. The distance of the backwards movement results from these deformation characteristics.

Sled tests

To analyse whether the new seat slide offers the possibility to prevent soft tissue neck injuries, sled tests were performed. A recent car seat from a European manufacturer was used and tested in its original configuration and with the new seat slide. The sled tests were carried out in collaboration with Autoliv (Germany) GmbH and all tests were performed in the same manner according to the test procedure for the evaluation of the injury risk to the cervical spine in a low speed rear-end impact proposed for the ISO/TC22 N 2071 and ISO/TC22/SC10, respectively [Muser et al. 1999, Muser et al. 2002].
The seats were mounted on the sled and adjusted such that the angle of the seat ramp and the recliner read

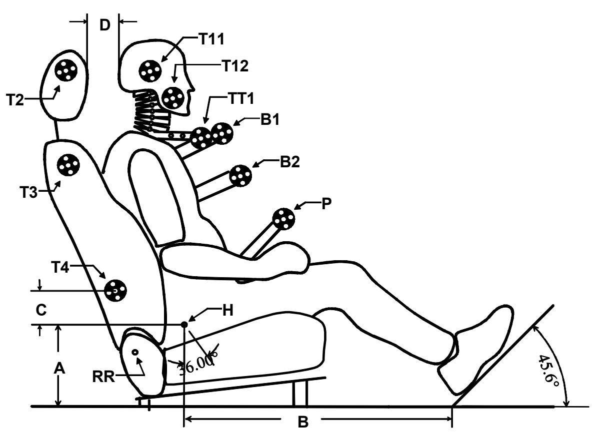

Figure 4. Principle of the test set-up for the sled tests including the measurement targets on the seat and the BioRID dummy.

12°± 1° and 25°± 2°, respectively. An H-point machine according to SAE J 826 was used for the adjustments.
As an anthropomorphic test device (ATD), a BioRID was used. The dummy was positioned in the seat according to the procedures described in ECE R 94. The ATD was instrumented with accelerometers located at the head, lower neck, chest and pelvis. On the upper neck (C1 level) forces in x and z direction were recorded and the bending moment around the y axis was measured. Figure 4 shows the test set-up. The seating posture was similar to the one in the original seat. Targets fixed to the seat base and to the seat slide were used to analyse the translational motion.
The crash pulse used in the tests was a trapezoidal shaped pulse with an average sled deceleration of 6 ± 1g and with rise and fall times of 10 - 20 ms. The resulting change of velocity (Δv) of the sled was 16 ± 1km/ h.
As for the evaluation, the neck injury criteria NIC_{max} [Bostrom et al. 1996] and N_{km} [Schmitt et al. 2002] were calculated using the following equations:

$$NIC(t) = 0.2 \cdot a_{rel}(t) + (v_{rel}(t))^2 \quad (1)$$

$$N_{km}(t) = \frac{F_x(t)}{F_{int}} + \frac{M_y(t)}{M_{int}} \quad (2)$$

where a_{rel} and v_{rel} denote for the relative acceleration and velocity of the highest (occipital condyles) and lowest (C7/T1) point of the cervical spine, respectively. NIC_{max} is the maximum value of the NIC(t) curve during the retraction phase. Currently the critical limit for the NIC_{max} is $15 m^2/s^2$ [Bostrom et al. 1996].
$F_x(t)$ and $M_y(t)$ are the shear force and the flexion/ extension bending moment, respectively. Both values are obtained from the load cell positioned at the upper neck. F_{int} and M_{int} represent critical intercept values

Table 1.

Results from the sled test experiments: time of head contact, NIC_{max} (top), and N_{km} values (bottom).

seat	head contact	NICmax	
	t [ms]	NIC_{max} [m2/s2]	t [ms]
reference seat	62	13.4	63
profile 1 (8 mm)	92	10.7	63
profile 2 (5 mm)	80	8.1	66

seat	N_{km}							
	N_{ep}	[ms]	N_{fp}	[ms]	N_{ea}	[ms]	N_{fa}	[ms]
reference seat	0.24	101	0.23	97	0.02	169	0.07	64
profile 1 (8 mm)	0.26	155	0.45	126	0.05	81	0.05	96
profile 2 (5 mm)	0.22	140	0.34	113	0.00	--	0.06	81

used for normalisation. The threshold value currently proposed is 1.0 for all possible N_{km} load cases [Schmitt et al. 2002].

RESULTS

Table 1 summarises the according results for the reference seat and two seats both equipped with the seat slide but using different deformation profiles. These profiles were of similar geometry (as shown in Figure 3) but with different thickness (8 mm and 5 mm). The deformation characteristics of the profiles along with the design of the seat slide resulted in a backwards motion of approx. 40 mm for all deformable slides. Figure 5 illustrates the deformation characteristics.

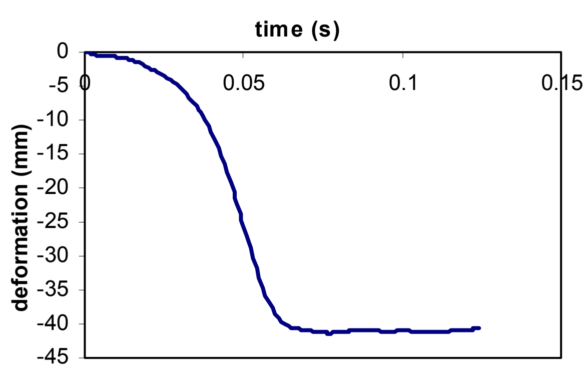

Figure 5. Deformation of a steel profile.

The NIC_{max} values were reduced from 13.4 of the reference seat to 8.1 for a modified seat. The N_{km} values were all - even for the reference seat - well below the proposed threshold and only slight differences between the seats were observed. The rebound velocities were also very similar for all tests, not indicating any significant changes caused by the seat slide.

Results for the pelvis acceleration are shown in Figure 6. The influence of the damping device is clearly indicated by the plateau value which limits the acceleration for a certain time and therefore causes the increase of the pelvis acceleration to be delayed. The change of the pelvis acceleration consequently affects the acceleration of the first thoracic vertebra (T1). This is also reflected in the NIC_{max} values (Figure 6).

Using the seat slide with the 5 mm profile the T1 acceleration is reduced in the retraction phase (i.e. when NIC_{max} occurs) and its maximum is shifted such that it meets the maximum of the head acceleration. The T1 and head acceleration peak values, however, were slightly increased. To check for the effect of this increase, the head injury criterion HIC was calculated. The HIC values obtained are 75 for the reference seat, 122 for the 8 mm profile, and 105 for the 5 mm profile, respectively.

Concerning the timing, a later head contact resulting in a later maximum of the head acceleration is observed due to the additional translational motion. The N_{km} values were also reached later in time than for the reference seat except for the Nea where the timing was inconsistent. The NIC_{max} occurred at about the same time for all seats.

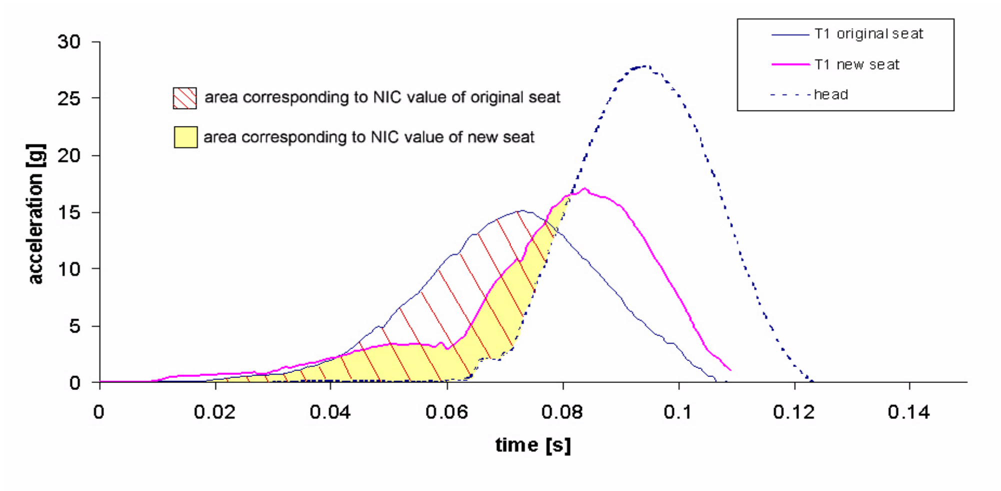

Figure 6. Pelvis acceleration for the reference seat and the seat equipped with the new slide and a 5 mm deformation profile. Additionally, a typical head acceleration curve is shown. The reduction of the NICmax is indicated schematically by the according areas.

Additionally, profiles of different geometry and from different materials were tested. Those results were either comparable or did not improve the behaviour of the seat in terms of neck injury criteria and are therefore not discussed here.

DISCUSSION

In order to develop a countermeasure for whiplash injury, a new seat slide was presented. The seat slide allows a translational backwards motion of the seat during a low-speed rear-end impact while damping this movement. A prototype of the seat slide was built using deformable steel profiles to damp the motion. The prototype was mounted to a standard car seat and sled tests were performed to analyse the potential of injury prevention of such a device. It was shown that the seat slide reduced the NIC_{max} to approximately 60 % of the value of the reference seat without such a slide. This indicates the benefit of controlled damping to reduce neck loading, especially to prevent the so-called S-shape which is assessed by the NIC_{max} . The higher head acceleration can be partly be attributed to the increased time interval until the head contacts the head restraint. In addition, the recliner properties that govern the relative velocity between head and head restraint are possibly accounting for a higher head acceleration. When the head impacts the head restraint (and thus is accelerated), the backrest and with it the head restraint have a slightly higher velocity relative to the head. The reason for such higher velocity can probably be found in the longer period for which the backrest is accelerated before head impact. The according HIC values reflect that behaviour, although they are all far below any threshold. Future work will analyse this behaviour more closely.

The relative motion between head and neck was reduced, because the timing of the according head and T1 acceleration was improved such that both accelerations reach their maximum at the same time. Furthermore, the outcome for the N_{km}, and the rebound velocities as well as the sitting posture of the dummy were not significantly influenced by the seat slide. Nonetheless, the influence of the seat slide on the head acceleration, for instance, demonstrates that a seat must be considered as a unit, i.e. a balanced seat design is - in the context of crashworthiness - only achieved by taking all seat components into account. Hence the construction of the seat slide, especially the characteristics of the deformable elements, has also to take those components into account. For the seat tested here this holds particularly true for the recliner which seems to have a large influence on the overall seat behaviour.

As for the pure translational motion of 40 mm, this distance seems acceptable for all two-seaters and for seats where the backrest does not (dynamically) rotate much like the one analysed here. Further tests with other seats will investigate whether there arise problems for backseat passengers such that the translation should be limited.

In general, the prototype proved to be repair friendly. Only the damping elements had to be replaced after a test. Furthermore, a system of this kind seems suitable to be fitted to different seats by adapting the profiles. As required the new system did not interfer with the translational adjustability of the seat, i.e. the seat remained adjustable after the impact.

Consequently, applying the principle of a damping seat slide shows that besides the recliner and the head restraint that are used in existing systems like WHIPS, WipGARD, and SAHR, the seat slide has the potential to prevent whiplash injury.

CONCLUSIONS

The design of a new seat slide to prevent whiplash injury is presented. A damping element was introduced that deforms during a translational backwards motion of the seat in case of a low-speed rear-end impact. The results indicate that such a design has a potential to improve the seat behaviour, particularly with respect to the relative acceleration between head and neck. A 40% reduction of the value for the neck injury criterion NIC_{max} was obtained. Although the design of the prototype is not yet suited for the production of larger numbers, the concept has proven to be suitable for such a purpose. Together with other systems presented, the new seat slide showed that for future car seats different possibilities concerning all major seat components are available to implement whiplash countermeasures.

ACKNOWLEDGEMENTS

We are gratefully indebted to the Swiss Funds of Traffic Safety for their support.

REFERENCES

Bostrom O, Svensson M, Aldman B, Hansson H, Haland Y, Lovsund P, Seeman T, Suneson A, Saljo A, Ortengren T (1996): A new neck injury criterion candidate based on injury findings in the cervical spinal ganglia after experimental neck extension trauma; *Proc. IRCOBI Conf.*; pp. 123-136

Eichberger A, Steffan H, Geigl B, Svensson M, Bostrom O, Leinzinger P, Darok M (1998): Evaluation of the applicability of the neck injury criterion (NIC) in rear end impacts on the basis of human subject tests; Proc. IRCOBI Conf.; pp. 153-161

Ferrari R (1999): The whiplash encyclopedia; Aspen Publishers Inc.; Gaithersburg

Hell W, Langwieder K, Zellmer H (2001) Biomechanics of cervical spine injuries in rear end car impacts, influence of car seats and possible evaluation criteria, Proc. IIWPG/IRCOBI Symposium, Isle of Man

von Koch, Kullgren A, Lie A, Nygren A, Tingvall C (1995) Soft tissue injury of the cervical spine in rear-end and frontal car collisions, Proc. IRCOBI Conf., pp. 273-282

Lundell B, Jakobsson L, Alfredsson B, Lindstrˆm M, Simonsson L (1998): The WHIPS seat - a car seat for improved protection against neck injuries in rear-end impacts, Proc. 16th ESV Conference, Paper No. 98-S7-O-08

Muser M, Walz F, Zellmer H (2000): Biomechanical significance of the rebound phase in low speed rear end impacts; Proc. IRCOBI Conf.; pp 411-424

Muser M, Zellmer H, Walz F, Hell W, Langwieder K (1999) Test procedure for the evaluation of the injury risk to the cervical spine in a low speed rear end impact, Proposal for the ISO/ TC22 N 2071 / ISO/TC22/SC10 (collison test procedures), http://www.biomed.ee.ethz.ch/~agu/

Muser M, Walz F, Schmitt K-U (2002) Injury criteria applied to seat comparison tests, Traffic Injury Prevention, Vol. 3 (3), pp. 224 - 232

Ono K, Kaneoka K, Imami S (1998): Influence of seat properties on human vertebral motionand head/ neck/torso kinematics during rear end impacts; Proc. IRCOBI Conf.; pp. 303-321

Schmitt K-U, Muser M, Walz F, Niederer P (2002): N_{km} - a proposal for a neck protection criterion for low speed rear-end impacts; Traffic Injury Prevention, Vol. 3 (2); pp. 117-126

Temming J, Zobel R (1998): Frequence and risk of cervical spine distortion injuries in passenger car accidents: significance of human factors data; Proc. IRCOBI Conf.; pp. 219-233

Viano D, Davidsson J (2001) Neck displacements of volunteers, BioRID P3 and Hybrid III in rear impacts: implications to whiplash assessment by a neck displacement criterion (NDC), Proc. IIWPG/IRCOBI Symposium, Isle of Man

Wiklund C, Larsson H (1998): Saab active head restraint (SAHR) - seat design to reduce the risk of neck injuries in rear impacts; SAE paper 980297

Yoganandan N, Pintar F (Eds.) (2000): Frontiers in whiplash trauma: clinical & biomechanical; IOS Press; Amsterdam

Zellmer H, Stamm M, Seidenschwang A, Brunner A (2001) Benefit from a neck protection system for aftermarket fitting, Proc. IRCOBI Conf., pp. 337-338